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(54) Title: APPARATUS FOR SEPARATING PARTICLES FROM A FLUID FLOW		
(57) Abstract		
<p>The invention provides apparatus for separating particles from a fluid flow having a cyclonic separator (10) and a fan (12) for causing the fluid to flow through the cyclonic separator (10), the cyclonic separator (10) having an inlet (16) and an interior wall having a frusto-conical portion (18) tapering away from the inlet (16), wherein the fan (12) is positioned in the inlet (16) to the cyclonic separator (10) such that fluid passing through the fan (12) is accelerated towards the interior wall (18) and thereby given sufficient tangential velocity to cause cyclonic separation of particles from the fluid flow within the cyclonic separator (10).</p>		

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Apparatus for Separating Particles from a Fluid Flow

The invention relates to apparatus for separating particles from a fluid flow, particularly but not exclusively to apparatus incorporating a cyclonic separator for separating dirt and dust particles from an airflow.

Cyclonic separators for separating particles from a fluid flow are well known. Within the last 15 years, many developments have been made in relation to the use of cyclonic separators within vacuum cleaners. Examples of such developments are EP 0018197, EP 0134654, EP 0489565 and EP 0636338. Inevitably there is always a desire to make cyclonic separators more efficient; that is to say, to produce a cyclonic separator which will separate a higher proportion of particles of a given diameter than comparable cyclonic separators. Constraints of size, cost and materials mean that the basic characteristics of cyclonic separators specifically intended for use in vacuum cleaners cannot be varied outside particular limits. Therefore, other ways of improving the cyclonic separator's efficiency have to be explored.

Basic cyclone theory states that there are two opposing forces acting radially on a particle travelling within a fluid flow. A centrifugal force F_z acts radially outwards on the particles, pressing them towards the cyclone wall, given by

$$F_z = (\rho_p - \rho) V_{t,p}^2 \frac{\pi x^3}{6r}$$

where	ρ_p	=	particle density, kg.m ⁻³
	ρ	=	fluid density, kg.m ⁻³
	$V_{t,p}$	=	tangential velocity of particle, m/s
	x	=	particle diameter, m
	r	=	radius of particle orbit, m

However an opposing drag force F_w acts towards the centre of the cyclone given by

$$F_w = C_D \rho \frac{\pi X^2}{8} (V_r - V_{r,p})$$

where

V_r	=	radial velocity of fluid, m/s
$V_{r,p}$	=	radial velocity of particle, m/s
C_D	=	drag coefficient (drag force per unit projected particle area/dynamic pressure)

When F_z exceeds F_w , the particle is thrown against the cyclone wall and separated from the air flow. When F_w exceeds F_z , the particle remains entrained within the air flow and exits the cyclone separator with it. Clearly it is highly advantageous to give F_z as large a value as possible. Since F_z is proportional to the square of the particle's tangential velocity, increasing the tangential velocity of the fluid will increase the cyclone's efficiency.

A parameter which is important in cyclonic separator theory is the cut diameter or cut point. This is the diameter of particle of which, for specified fluid flow conditions, 50% are removed by the cyclone and 50% remain entrained. The cut point is a measure of the separation efficiency of the cyclone: the lower the cut point for given conditions, the lower the proportion of particles remaining in the fluid flow; therefore, the higher the separation efficiency. It is therefore desirable to achieve as low a cut point as possible for specified conditions.

Semi-empirical cyclone theory has been developed to give an expression for the cut size X_{50} for which 50% of the particles are collected.

$$X_{50} = \sqrt{\frac{k Q \mu}{\rho_p V_t^2}}$$

where

Q	=	volumetric flow rate, m^3/s
μ	=	viscosity, kg/ms
k	=	geometric factor
V_t	=	tangential velocity, m/s

The theory states that V_t in the cyclone vortex is a linear function of Q . This suggests that the cut size can be decreased by increasing V_t (i.e. $X_{50} \propto \sqrt{1/V_t}$) and hence increasing the separation efficiency.

The computation of the separation efficiency for a range of particle sizes (commonly known as the grade efficiency curve) also depends on the cyclone parameters and flow characteristics of the fluid. The separation efficiency can be expressed empirically, for any particle size, as:

$$\xi = \left[1 + \left(\frac{k V_t^2 \rho_p x^2}{\mu Q} \right)^{-3.2} \right]^{-1}$$

This also suggests that, for any fixed cyclone design and particle size, the separation efficiency is governed by the tangential velocity and the volumetric flow rate, the latter of which is related to the former. Hence, again, the separation efficiency will increase as the tangential velocity increases.

All of the above theory indicates that the efficiency of a cyclone can be increased by increasing the tangential velocity. The simplest way to achieve such an increase is merely to provide a more powerful motor to create a higher rate of fluid flow. Unfortunately, there are limits to the type of motor which can be utilised in some applications such as, for example, domestic vacuum cleaners. Such motors are limited by factors such as physical size, weight and cost. For this type of application other ways of increasing the tangential velocity of the fluid flow at the inlet to the cyclone must be sought.

It has long been recognised that fluid leaving a fan which incorporates rotating impeller blades has a tangential velocity component. Until now, no truly effective use has been made of that tangential component in cyclonic separators. The fan has always been located at a position remote from the cyclone inlet, normally downstream of the separator, so that all of the tangential velocity of the fluid entering the cyclone has to be forcibly applied to the fluid flow upstream of the cyclone. The forced application of a

tangential velocity component inevitably causes slight decreases in the flow rate overall due to friction losses.

It is therefore an object of the invention to provide apparatus for separating particles from a fluid flow having a cyclonic separator which, for given conditions, has a higher inlet tangential velocity and therefore a higher separation efficiency than corresponding known separators. It is a further object of the invention to provide apparatus for separating particles from a fluid flow having a cyclonic separator which makes advantageous use of the tangential velocity component of fluid leaving a fan. A further object of the invention is to provide apparatus for separating particles from a fluid flow having a cyclonic separator which is efficient, compact, lightweight and easy to service and maintain.

The invention provides apparatus as set out in claim 1. The location of the fan in the inlet to the cyclonic separator means that relatively high inlet tangential velocities can be achieved within the cyclone due to lower losses, hence improving the efficiency of the cyclone. This maximises the utilisation of the tangential velocity imparted to the fluid flow by the fan. Also, the airflow through the separator per unit of power consumed is improved. Further advantageous features are set out in the subsidiary claims. It will be noted that, contrary to the arrangement in virtually all known cyclonic vacuum cleaners, the fluid flow is in this case pushed through the cyclone separator instead of being pulled or sucked.

Embodiments of the invention will now be described with reference to the accompanying drawings, wherein:

Figure 1 is a schematic longitudinal sectional view of a cyclonic separator and fan according to a first embodiment of the invention;

Figure 2 is a cross section taken on line II-II of Figure 1; and

Figure 3 is a view, similar to Figure 1, of a second embodiment of the invention.

The apparatus shown in Figures 1 and 2 consists of a cyclonic separator 10, a fan 12 and a motor 14. The cyclonic separator 10, which in this embodiment forms part of a vacuum cleaner, is essentially of standard construction comprising an upper cylindrical wall 16 located at the upper edge of a conical tapering cyclone wall 18 which leads to a cone opening 20. Sealingly attached to the outer surface of the

cyclone wall 18 and surrounding the cone opening 20 is a collecting chamber 22 which has an outer diameter of at least three times that of the cone opening 20. The collecting chamber 22 is removable to allow dirt and dust collected therein to be disposed of. An exit port 24 is provided at the upper end of the cyclonic separator 10, coaxial with the longitudinal axis 28 of the cyclone wall 18 and collecting chamber 22, and communicating with the downstream path (not shown) of the fluid from which particles are to be separated.

A conventional cyclonic separator would have an inlet port consisting of an entry conduit arranged to introduce an airflow into the cyclonic separator 10 tangentially to the upper cylindrical wall 16 under the influence of a motor and fan arranged downstream of the cyclonic separator. This type of arrangement can be seen in the prior art documents mentioned above. The apparatus of the present invention utilises a different entry arrangement but, downstream of the inlet port, the operation of the cyclonic separator is the same. Downstream of the inlet port, the airflow moves along a spiral path down the inside of the cyclone wall 18, increasing in speed as it progresses, until it emerges through the cone opening 20 into the collecting chamber 22. Larger particles previously entrained within the airflow are flung against the outer wall of the collecting chamber 22 and collected therein. Inevitably, and in accordance with the theory outlined above, some smaller particles remain entrained and they exit the collecting chamber 22 with the airflow via the cone opening 20 and pass generally along the axis 28 to the exit port 24 and from there to the downstream airflow path.

The above arrangement and separation operation are known. The difference between the apparatus described above and the apparatus of the invention lies in the inlet port. Instead of providing a tangential entry port into the upper end of the cyclonic separator, the apparatus of the present invention provides a fan 12 positioned centrally within the inlet to the cyclonic separator 10. Indeed, in the embodiment shown, the fan 12 is located within the upper cylindrical wall 16 and is rotatable about the longitudinal axis 28 of the cyclone wall 18 (see arrow 30). The fan 23 is of standard design and has a plurality of impeller blades 32 whose rotation causes the airflow to flow through the cyclonic separator, also accelerating the airflow towards the cyclone wall 18 and

imparting sufficient tangential velocity to cause cyclonic separation of dirt and dust particles from the airflow within the separator 10.

Located radially outwardly of the fan 12 is a plurality of vanes 34 which define a series of conduits 36 leading from the fan 12 to the upper cylindrical wall 16. These inlet conduits 36 guide the airflow so that it emerges adjacent the upper cylindrical wall 16 without losing its high tangential velocity. The high tangential velocity is achievable due to the fact that the tangential velocity provided to the airflow by the fan is present as the airflow reaches the upper cylindrical wall 16. Frictional losses due to the redirectioning of the fluid are minimal or relatively small. Therefore the tangential velocity of the airflow in the cyclonic separator 10 is higher than the known equivalent cyclonic separator mentioned above and the separation efficiency of the cyclone is improved. Since the losses inherent in the arrangement are smaller than those inherent in the known equivalent separator, the airflow through the separator per unit of power consumed is also improved.

In the embodiment shown, the motor 14 is located immediately adjacent the fan 12. This arrangement is simple and efficient. However, the location of the fan 12 and motor 14 above the cyclonic separator 10 and coaxially therewith means that the exit port 24 of the cyclonic separator 10 cannot take its normal route out of the cyclone along the same axis 28. The problem is solved in the illustrated embodiment by providing outlet conduits 38 between the inlet conduits 36, the outlet conduits 38 being connected to the outlet port 24 by other passageways or conduits or by an exit chamber 40 extending radially outward from the exit port 24 towards the upper cylindrical wall 16. The airflow exiting the cyclonic separator 10 can be led through convoluted passages if desired since, once separation has been completed, it is no longer necessary to maintain a high flow rate. The exiting airflow can be led past the motor 14 for cooling purposes if desired.

A second embodiment of the invention is illustrated in Figure 3. The arrangement shown in Figure 3 is identical to that shown in Figure 1, with the exception of the positioning of the motor 14' which drives the fan 12. In Figure 3, the motor 14' is positioned below the collecting chamber 22 and has a drive shaft 42 passing through the collecting chamber 22, the cyclonic separator 10 and the exit port 24, along the

longitudinal axis 28 thereof. The drive shaft 42 is directly connected to the fan 12, which occupies the same position in Figure 3 as it does in Figure 1.

The positioning of the motor 14' below the collecting chamber 22 in the embodiment of Figure 3 has the advantage of lowering the centre of gravity of the vacuum cleaner as a whole compared to the embodiment shown in Figure 1. This is advantageous for stability reasons. If the motor 14' is positioned as shown in Figure 3, the fan 12 can include passageways to allow the exiting air to pass out of the separator along the axis 28 instead of through the outlet conduits 38. This simplifies the structure and reduces manufacturing costs.

It will be appreciated that, if desired, the vanes 34 can be omitted and the air exiting the fan 12 can be directed towards the cyclone wall solely by the fan's impellers. It will further be appreciated that the fan, shown in the embodiments as a radial fan, can be an axial fan which would also impart tangential velocity to the airflow passing therethrough.

The invention described above is suitable for use in vacuum cleaners, particularly domestic vacuum cleaners. The repositioning of the fan to a position within the inlet to the cyclonic separator takes full advantage of the fact that the air (or other fluid) exiting the fan has a tangential velocity component and this is used to enhance the inlet tangential velocity and hence the efficiency of the cyclonic separator. In vacuum cleaners incorporating two cyclonic separators, it is preferable for the fan to be positioned immediately upstream of the second, high efficiency cyclonic separator, partly to enhance the separation of fine dust particles, but also to ensure that larger particles are removed from the airflow before passing through the fan. This will reduce wear to the fan and also reduce the risk of damage occurring during operation. The positioning of the motor directly adjacent the fan as shown in Figure 1 provides a compact unit which can be easily accessed or removed for maintenance and/or repair. However, providing a drive shaft as shown in Figure 3 can allow the motor to be used for other purposes within the appliance if necessary. It is envisaged that some applications of cyclonic separators may utilise two or more separators similar to the one illustrated and described above and each separator may require its own fan.

Appropriate positioning of the separators would allow two or more fans to be driven directly by the same motor.

For the purposes of illustration only, the following dimensions are given as an example of a cyclonic separator of the type shown in Figure 1 and suitable for use in a domestic vacuum cleaner:

Diameter of fan 12:	109mm
Diameter of cylindrical wall 16:	140mm
Depth of cylindrical wall 16:	45mm
Depth of cyclone wall 18:	325mm
Diameter of cone opening 20:	25mm
Diameter of collecting chamber 22:	145mm
Diameter of upper part of collecting chamber:	80mm
Height of cone opening 20 above base:	70mm
Diameter of exit port 24:	32mm

It must be emphasised that this invention is not limited to separators for separating particles from an airflow or for use with a vacuum cleaner. The principles mentioned at the outset apply generally to most fluids and the apparatus can be used to separate particles from vehicle exhaust fumes, water other liquids and other gases. The fact that the preferred application at the time of filing is in vacuum cleaners is not intended to be limiting.

CLAIMS

1. Apparatus for separating particles from a fluid flow having a cyclonic separator and a fan for causing the fluid to flow through the cyclonic separator, the cyclonic separator having an inlet and an interior wall having a frusto-conical portion tapering away from the inlet, wherein the fan is positioned in the inlet to the cyclonic separator such that fluid passing through the fan is accelerated towards the interior wall and thereby given sufficient tangential velocity to cause cyclonic separation of particles from the fluid flow within the cyclonic separator.
2. Apparatus as claimed in claim 1, wherein a plurality of vanes defining a series of inlet conduits are provided between the fan and the interior wall of the cyclonic separator.
3. Apparatus as claimed in claim 2, wherein the vanes follow a generally spiral path when viewed along the central axis of the cyclonic separator.
4. Apparatus as claimed in any one of the preceding claims, wherein the cyclonic separator includes an exit port through which the fluid from which particles have been separated leaves the cyclonic separator, the exit port comprising at least one outlet conduit for directing the said fluid radially outwardly towards the interior wall of the cyclonic separator.
5. Apparatus as claimed in claim 4, wherein a plurality of outlet conduits are provided.
6. Apparatus as claimed in claim 2 or 3 and claim 5, wherein the number of inlet conduits is the same as the number of outlet conduits.
7. Apparatus as claimed in claim 6, wherein the inlet conduits and outlet conduits are arranged alternately about the central axis of the cyclonic separator.

8. Apparatus as claimed in any one of the preceding claims, wherein a motor is provided for driving the fan, the motor being located adjacent the fan.
9. Apparatus as claimed in claim 8, wherein the fluid flow is arranged to cool the motor.
10. Apparatus as claimed in any one of the preceding claims, wherein an upstream particle separator is provided upstream of the fan.
11. Apparatus as claimed in claims 8 or 9 and 10, wherein the upstream particle separator is located upstream of the motor.
12. Apparatus as claimed in claim 10 or 11, wherein the upstream particle separator is a second cyclonic separator.
13. Apparatus as claimed in any one of claims 1 to 7, wherein a motor is provided for driving the fan, the motor having a drive shaft connected to the fan and passing through the cyclonic separator along the central axis thereof.
14. Apparatus as claimed in claim 13, further comprising a second cyclonic separator and a second fan for causing the fluid to pass through the second cyclonic separator, wherein the drive shaft is connected to the second fan.
15. Apparatus as claimed in any one of the preceding claims, wherein the fan is positioned centrally in the inlet to the cyclonic separator.
16. Apparatus as claimed in any one of the preceding claims, wherein the interior wall comprises an upper cylindrical portion from which the frusto-conical portion tapers away, the fan being positioned within the upper cylindrical portion.

17. Apparatus as claimed in any one of the preceding claims, wherein the fluid intended to be treated is air.
18. Apparatus for separating particles from a fluid flow substantially as hereinbefore described with reference to the accompanying drawings.
19. A vacuum cleaner incorporating apparatus as claimed in claim 17.

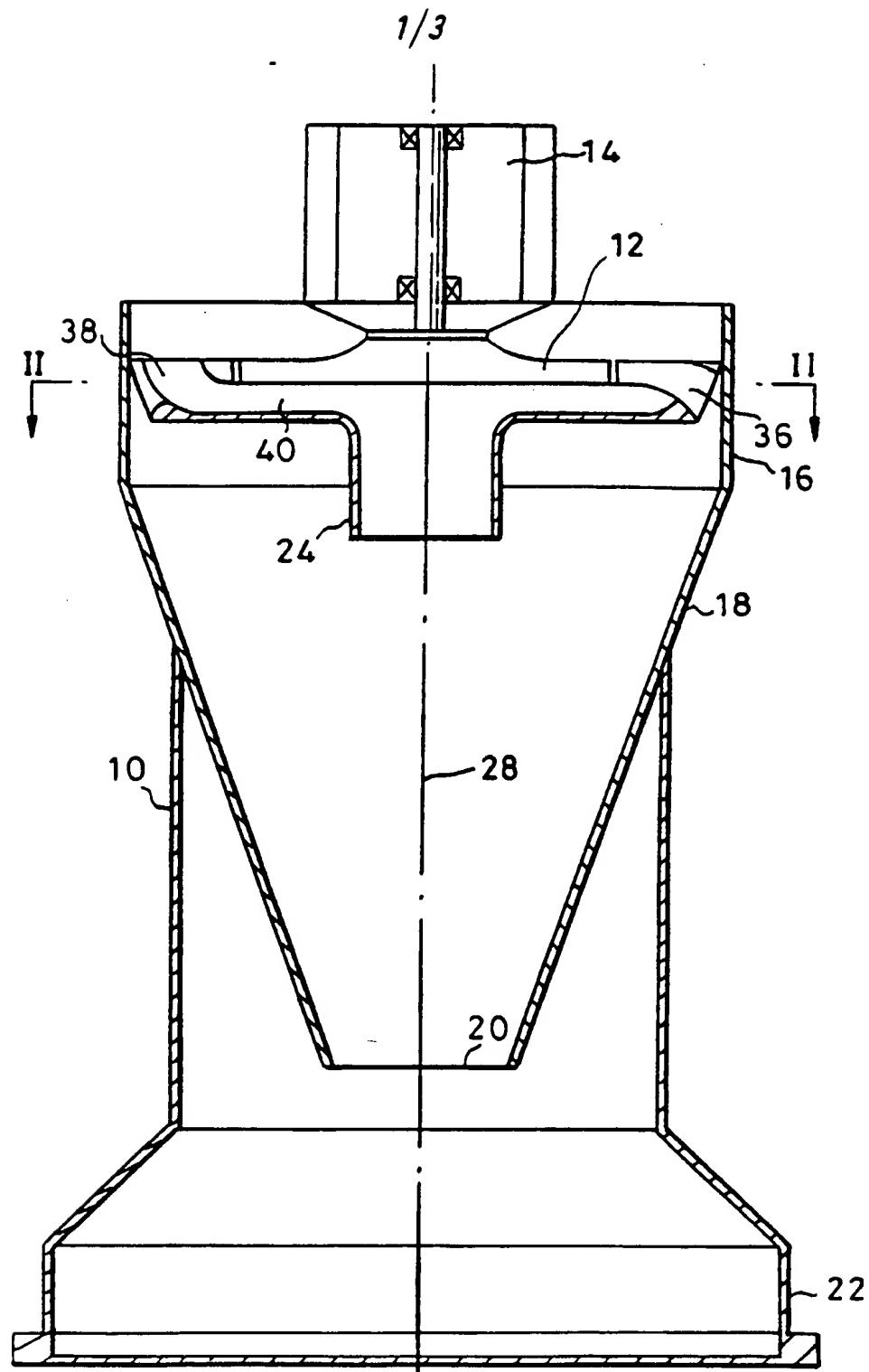


FIG.1

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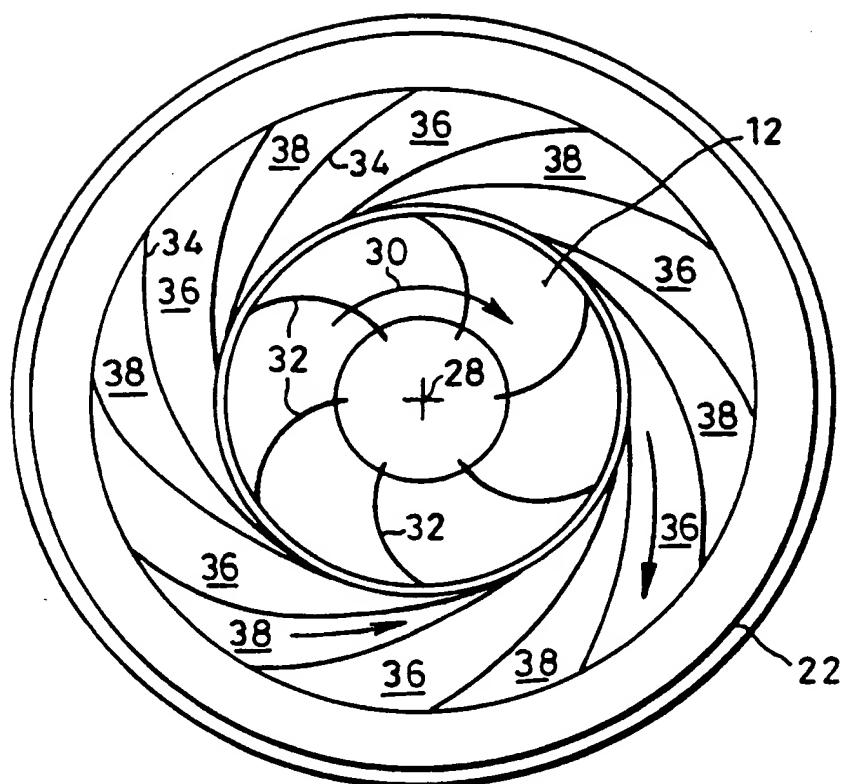


FIG.2

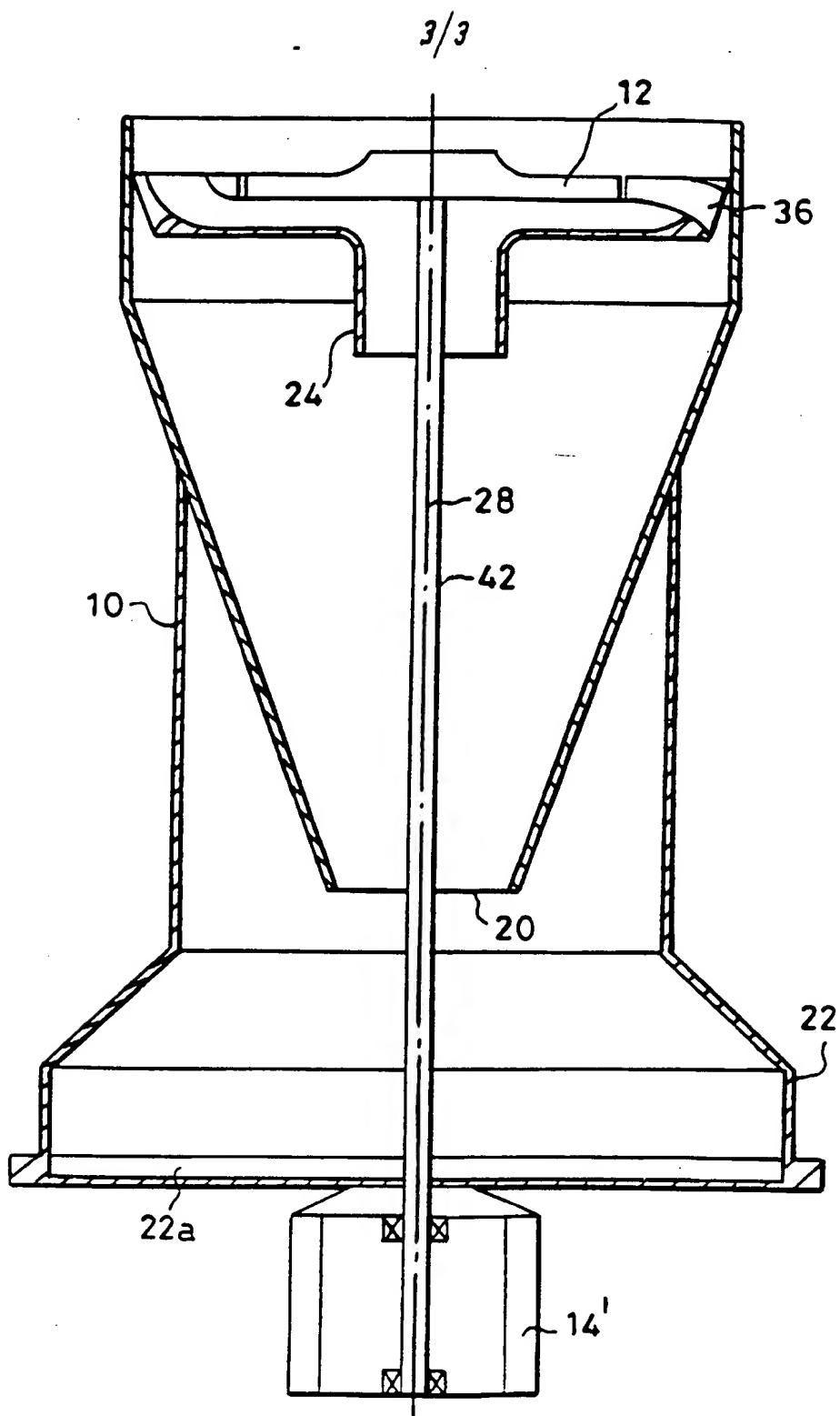


FIG. 3

INTERNATIONAL SEARCH REPORT

Int. - onal Application No PCT/GB 97/03244

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B04C9/00 A47L9/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B04C A47L B07B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 1 077 243 A (SANDERS ET AL) 5 November 1954 see page 3, left-hand column, line 40 - right-hand column, line 41 see page 4, left-hand column, line 14 - line 46 see page 4, right-hand column, line 32 - page 5, left-hand column, line 41; figures	1,4,5, 15,16
A	---	8
X	FR 2 344 670 A (HERMANN FINCKH MASCHINENFABRIK) 14 October 1977 see page 4, line 41 - page 7, line 18; figures	1,4,5,16
A	---	8,15
	-/-	

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
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- "O" document referring to an oral disclosure, use, exhibition or other means
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- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- "&" document member of the same patent family

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Date of the actual completion of the international search

20 February 1998

Date of mailing of the international search report

18.03.98

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INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 97/03244
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C(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 95 10972 A (SJÖGREEN) 27 April 1995 see abstract see page 6, line 20 - page 7, line 5 see page 8, line 15 - line 35; figures	1,10,12, 13,16, 17,19
A	---	4,8,14, 15
X	NTIS ENERGYGRAM, OAK RIDGE TN USA 'Cyclocentrifuge for Coal-Conversion Gas' Available at the EPO October 19,1981, XP002056347 based on NTIS Reports MTI-79TR16, FE-2428-10, FE2428-T1 see the whole document	1,16,17
A	-----	4,8,15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 97/03244

Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.: 18 because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
Not allowable; Rule 6.2 (a) PCT

3. Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int'l. Appl. No
PCT/GB 97/03244

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